Physical Parameterizations for the ESPC Coupled Global Prediction System

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LONG-TERM GOALS

Develop and implement a fully coupled global atmosphere/wave/ocean/land/ice prediction system capable of providing daily predictions out to 10 days and weekly predictions out to 30 days. Initial Operational Capability is targeted as 2018. Predictions will provide environmental information to meet Navy and DoD operations and planning needs throughout the globe from undersea to the upper atmosphere and from the tropics to the poles. The system will be implemented on Navy operational computer systems, and the necessary processing infrastructure will be put in place to provide products for Navy fleet user consumption.

OBJECTIVES

Develop and test coupled physical parameterizations for NAVGEM/HYCOM with a focus on the parameterizations that impact the coupling variables including surface winds and ocean currents, wind stress, heat and moisture fluxes, radiation fluxes, salt fluxes and sea surface temperature and salinity.

APPROACH

Several coupled ocean-atmosphere modeling systems have been developed, e.g., CESM, which couples CAM and MOM4 at climate scale and eddy resolving scales and CFS, which couples reduced resolution NCEP and MOM4. However, the Navy atmospheric forecast system (NAVGEM) and oceanic forecast sytem (HYCOM) have never been coupled at high resolution. The coupled processes will be incrementally tested in a controlled manner. That is, each step of the feedback loop must be examined and the effects validated. A range of physical processes will be included and excluded to ensure proper interactions between these processes. Both short term (10 day) and long term (30 day) tests will be conducted for this work.

We wiil perform tests on NAVGEM and HYCOM in uncoupled, loosely coupled, and two-way coupled modes. Testing on loose coupling can begin immediately. At present, the atmosphere provides fluxes to the ocean model, while the atmosphere obtains sea surface temperature (SST) from an independent analysis. There is no feedback. Initial tests will use hindcasts with analysis-quality results from HYCOM simulations to drive NAVGEM. This will provide a first indication of the impact and potential problems involved in the feedback process. The HYCOM SST analysis has been

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shown to be quite accurate because of the large amount of satellite sea surface temperature data available. However, as the forecast proceeds, the model physics dominate. Stand-alone HYCOM driven by atmospheric fluxes and without data assimilation develops biases in the SST. Reducing this biases to approach the analysis-quality SST requires flux corrections with are as large as the annual mean fluxes. In the loosely coupled simulations, a standard NAVGEM forecast with fixed analysis-quality SST will be made. This NAVGEM forecast will drive a HYCOM simulation. The time-varying HYCOM SST will be provided to NAVGEM for a reforecast. The NAVGEM reforecast using the time-varying HYCOM SST will then be used in a second run of HYCOM to document the first incremental changes that occur through the feedback mechanisms.

The above experiments will occur with each component using its own flux computation (the planetary boundary layer model for NAVGEM and bulk formulations for HYCOM). It is expected that the above work will reveal shortcomings in the flux parameterizations as non-conservative properties will occur. Addressing these issues will require implementation of different parameterizations and flux estimations to reduce the non-conservation. After new parameterizations are implemented, a new cycle of the above testing will be carried out. The systematic tests of different coupling variables, including surface wind, wind stress, heat and moisture fluxes, radiation fluxes, salt fluxes, sea surface temperature, and salinity will be performed.

We will test new NAVGEM surface physics for coupling. Additional physical processes at the interface will be added to extend flux parameterization including sea-spray effect, dissipative heating, frictional velocity, and surface roughness. We will test new bulk formulations of the momentum stress using the shear of winds and currents across the interface.

We will perform extended integrations of fully coupled realistic NAVGEM/HYCOM with modified physical parameterizations. We will identify forecast biases on key global circulation features in the atmosphere and ocean. We evaluate the coupled integrations for the DYNAMO intensive field experiment from October 2011 to January 2012, when there are several MJO events which require coupled models to characterize properly.

The key performers for this task are:

--James G. Richman, NRL: Richman is the oceanography lead for this task.

--James Ridout, NRL: Ridout is the meteorology lead for this task. He wrote the subroutines to accept the hourly SST fields from HYCOM for the 30 day NAVGEM forecasts

--E. Joseph Metzger, NRL: Metzger lead the effort to evaluate NAVGEM forcing fluxes for HYCOM, which provides the flux corrections used in stand-alone HYCOM.

--Deborah Franklin, QuinetiQ: Franklin prepares the NAVGEM boundary layer fields for ingest by HYCOM.

--Luis Zamudio, FSU: Zamudio performed the HYCOM runs with the reforecast NAVGEM forcing fluxes.

--Jay Shriver, NRL: Shriver performed the twin experiments evaluating the impact of the modified wind stress forcing.

--Carolyn Reynolds, NRL: Reynolds performed the 2011-12 NAVGEM hindcast to provide the fluxes for the initial evaluation.

--Maria Flatau, NRL: Flatau compared the NAVGEM fluxes to MERRA reanalysis fluxes.

WORK COMPLETED

The start of work on this task was delayed by two major events, the acquisition of new supercomputers at the DSRC and the switch from NOGAPS to NAVGEM as the operational NWP forecast system. The existing forecast models NAVGEM and HYCOM has to transitioned to the new computers which entailed modified both the source codes and runtime scripts. The project had to wait until a year-long time series of NAVGEM output exisited before the flux correction could be calculated and an initialized HYCOM state could be computed. An attempt was made to use a NOGAPS forced intitialization, which showed promise, but suffered from a large initial bias which couldn't be removed in the loosely coupled runs. Once, the NAVGEM forcing fields were calculated, a HYCOM hindcast was performed and a start on the loosely coupled runs begun. A set of twin experiments to look at the impact of modifying the wind stress to include the ocean surface currents was performed.
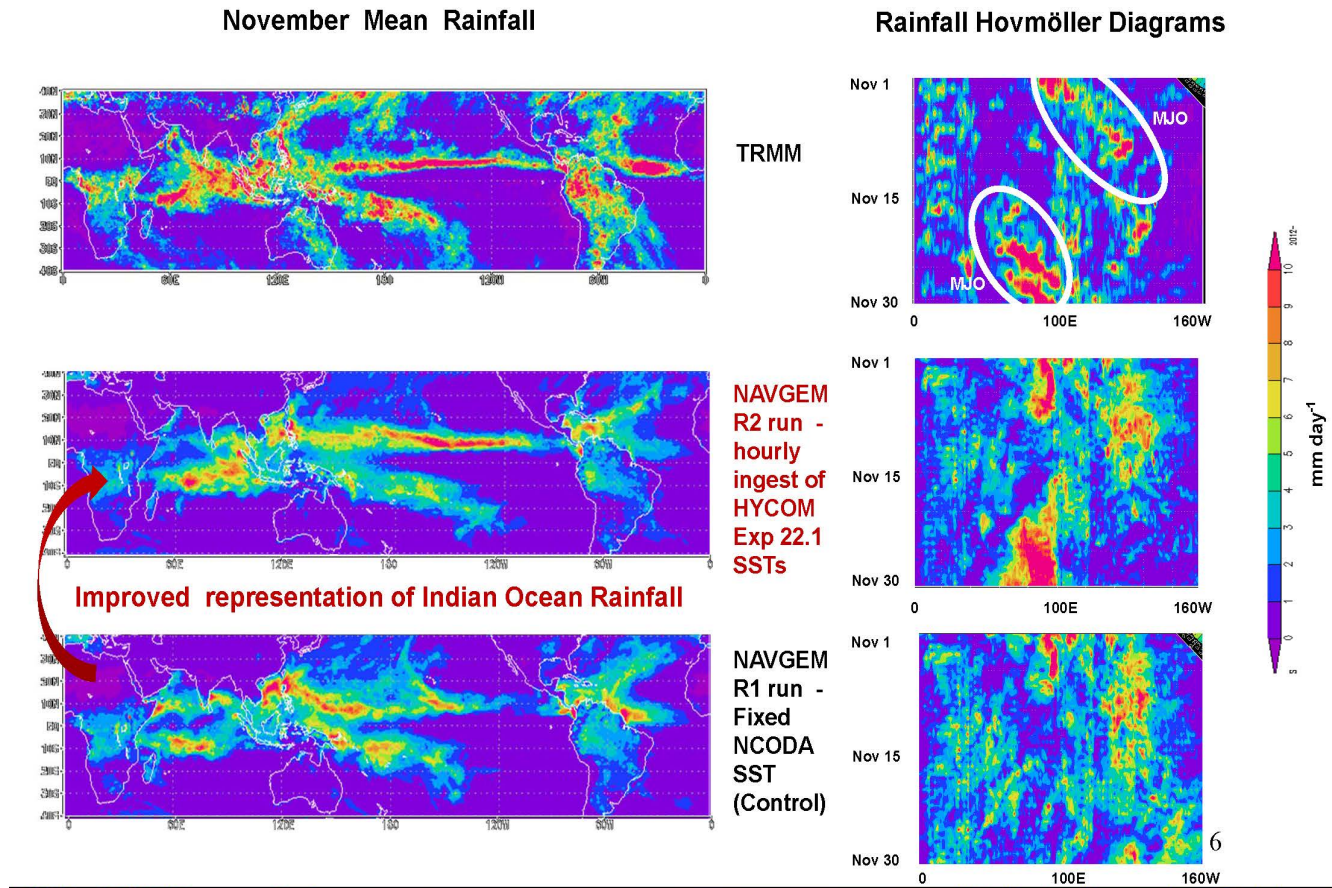
RESULTS

One problem found in most eddy-resolving general circulation models centers around the formation and propagation of Agulhas eddies in the Retroflection region. Previous work by McClean et al. (2011) and Anderson et al. (2011) suggests that modifying the wind stress to include the wind and current shear across the sea surface impacts the formation of eddies by boundary currents. In HYCOM, the Agulhas eddies formed are too strong, too regular in size and are generated in a too regular pattern and location. The Agulhas rings persist too long traveling across the South Atlantic to South America along a single pathway, which creates an unrealistic hot spot in the eddy kinetic energy. To test this new physical parameterization, twin experiments with (23.6) and without (23.2) the new shear formution were performed. The new shear formulation improves the Agulhas ring formation with weaker amplitudes and more diverse pathways as seen in the figure below. However, the new shear formulation does not solve the problem.
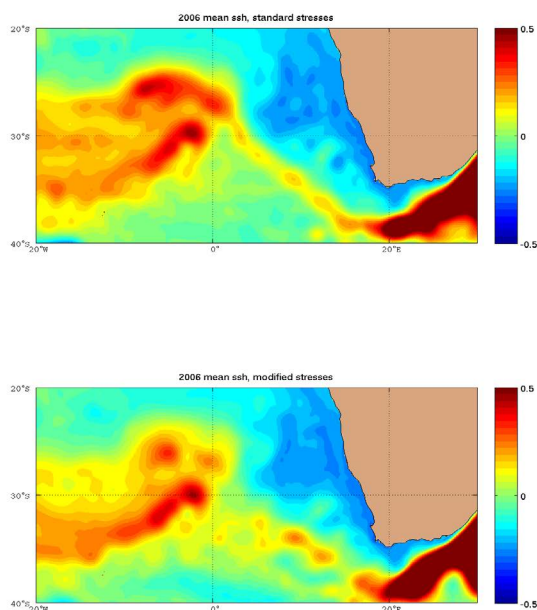
In the upper panel, the mean sea surface for 2006 is shown with the traditional momentum flux calculation. The Agulhas rings follow a single pathway which shows up as a ridge of elevated sea level stretching NW from the tip of South Africa. In the lower panel, where the momentum flux is modified to include the shear between the 10 m wind and the ocean surface current, the single ridge of elevated sea level is broken into two ridges indicating at least two pathways for the rings.
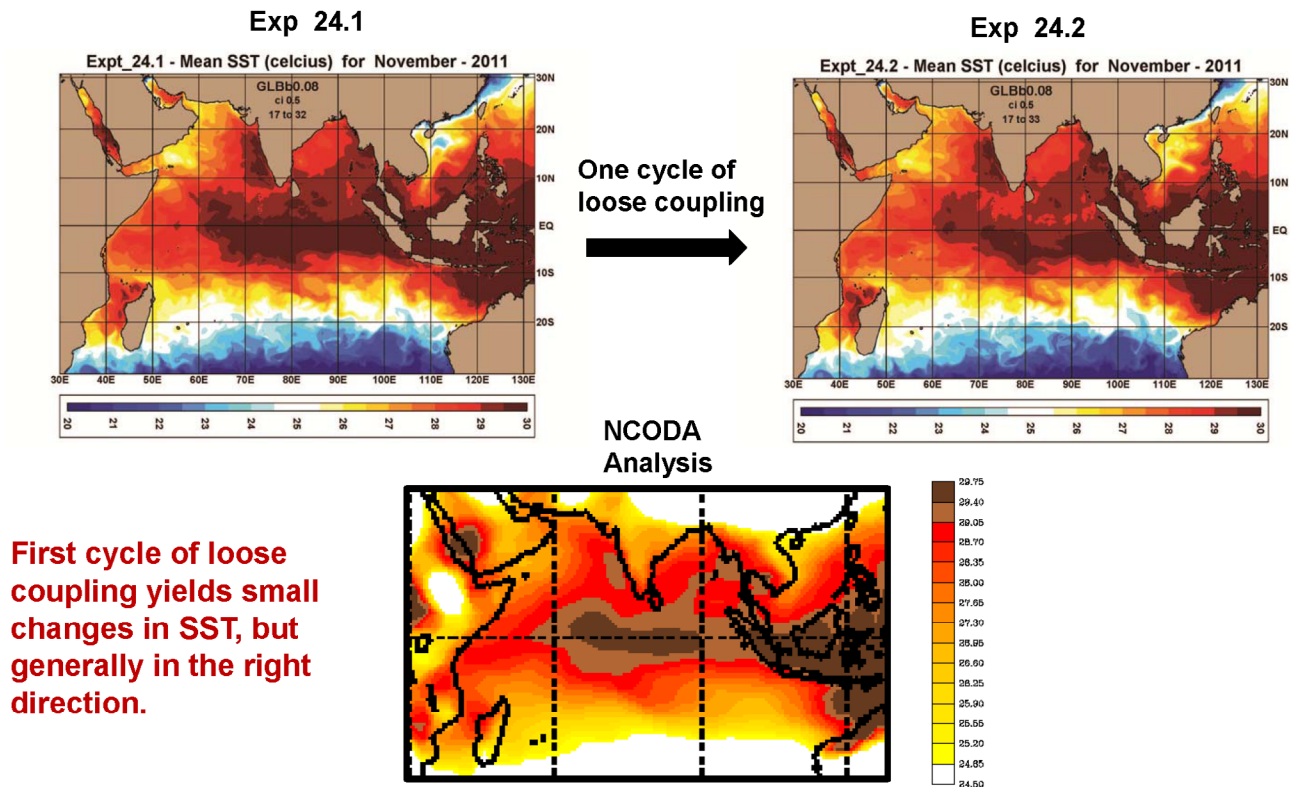
The loosely coupled simulations for a 30 day forecast during the DYNAMO period (November 2011) were begun. A NAVGEM hindcast was performed from mid-June 2011 to December 2011 in early 2013. At the time no NAVGEM climatology was available to

spinup HYCOM and perform a hindcast to start the loosely coupled runs. A version of HYCOM was spunup using a repeat of the operational forecast from March 2012 to February 2013 to provide the initial condition for HYCOM for the loosely coupled experiments. Using the cycle of forcing HYCOM with a 30 day NAVGEM forecast with fixed SSTs and then reforecasting NAVGEM for the same 30 days with time-varying SSTs improved the precipitation papers over the ocean as seen in the figure below.

November Mean Rainfall

Rainfall Hovmöller Diagrams

TRMM

NAVGEM R2 run - hourly ingest of HYCOM Exp 22.1 SSTs

Improved representation of Indian Ocean Rainfall

NAVGEM R1 run - Fixed NCODA SST (Control)

Comparing the rainfall in the two NAVGEM runs, R1 with fixed SST and R2 reforecast with hourly HYCOM SST, to TRMM for Nov 2011 shows a significant impact of the time-varying SSTs. The right hand panels show the hovmueller digagrams of the precipitation averaged from 5S to 5N with two westward propagating MJO events in the TRMM observations and a suggestion of the MJO events in the time-varying SST reforecast. However, the HYCOM initial condition had a large SST bias, which is decreased in the loosely coupled forecasts of HYCOM forced by R1 and then reforecst with R2, but the bias still exists as seen in the figure below.

Exp 24.1

Expt_24.1 - Mean SST (celcius) for November - 2011

Exp 24.2

Expt_24.2 - Mean SST (celcius) for November - 2011

One cycle of loose coupling →

NCODA Analysis

First cycle of loose coupling yields small changes in SST, but generally in the right direction.

A hindcast of HYCOM spunup from a "2 year climatology" and assimilating data has been made for mid-June 2011 to July 2012. The hindcast is providing a new initial condition for another loosely coupled experiment, but the second NAVGEM reforecast has not completed. The results from this new experiment will be used to begin a two-way coupled simulation with and without flux corrections.

IMPACT/APPLICATIONS

The results of these experiments will be used to develop a flux mediator for the two-way coupled ocean/atmosphere forecast system.

RELATED PROJECTS

This work is part of a larger ESPC project.

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